

DESIGN OF MICROSTRIP ANTENNA BASED ON DIFFERENT MATERIAL PROPERTIES

ANIS NABIHAH BINTI IBRAHIM

A project report submitted in partial fulfillment of the requirement
for the degree of
Master of Electrical Engineering



Faculty of Electrical and Electronics Engineering
Universiti Tun Hussein Onn Malaysia

JANUARI 2015

Special Dedication For...

My Husband,

Mr. Muhammad bin Mohamed Salleh,

Thank you for your sacrifices,

May Allah bless our marriage.

My Parents, Father In Law and Mother In Law,

Mrs. Azizah binti Samat and Mr. Ibrahim bin Daud,

Mr. Mohamed Salleh bin Kalil and Mrs. Siti Haida binti Othman,

Your sacrifices will always be remembered,

May Allah bless all of you.

My Beloved Family,

May Allah bless our lives,

May Allah grant our health, wealth and faith.

ACKNOWLEDGEMENT

In the Name of Allah the Most Gracious and the Most Merciful. Alhamdulillah, my praise to Allah s.w.t for giving me the strength to overcome all difficulties and letting me finish my Master's Project. In order to undergo this final year project, I would like to express my gratitude and appreciation to all those who gave me the possibility to complete this project. Without their help, full support and their contribution towards this project, I believe that this thesis will never be produced such a wonderful way.

First of all, I would like to take this opportunity to thank to my supervisor, *Dr. Rozlan bin Alias*, who gave me a lot of guidance and advices throughout this project. His kindness and toleration has giving me the spirit to carry out this job until the end and finally complete. My appreciation also goes to all lecturers and technicians that involved in this project direct or indirectly for their advices and supervisions. Special acknowledgement goes to my husband *Mr. Muhammad bin Mohamed Salleh*, and my parents *Mrs. Azizah binti Samat* and *Mr. Ibrahim bin Daud*, for their moral and financial supports. Their countless effort of encouragements made my journey pleasurable. Last but not least, this acknowledgement also goes to all my dearest family and friends, who are directly or indirectly giving me full support during the development of this project. Thank you very much and may Allah bless all of you.

ABSTRACT

Microstrip antenna has several advantages compared to conventional microwave antenna. These type of antenna are light weight, low volume and thin profile configurations, which can be made conformal. The cost of fabrication is also low and can be manufactured in a large quantities. This project will discuss about the microstrip antenna. The aim of this project is to design a microstrip antenna by using Flame Retardant 4 (FR4) substrate and Roger 4350 substrate which will be operating in Wireless Local Area Network (WLAN). The frequency chosen for the microstrip antenna is 2.4GHz and it has been chosen from IEEE 802.11 which is for the Wireless Fidelity (WiFi) network. This project is divided into three major parts which are calculation, simulation and hardware design. Computer Simulation Technology (CST) microwave studio software used to analyze the radiation pattern of the antenna before fabricated the antenna. Vector Network Analyzer (VNA) used to measure the fabricated antenna to obtain the measurement result. The simulation and measurement results shows a little bit differences for both of the material substrates. Comparison between simulation and measurement result has been made.

ABSTRAK

Antena Mikrojalur mempunyai beberapa kelebihan berbanding dengan Antena Gelombang Mikro Konvensional. Antena Mikrojalur mempunyai kos fabrikasi yang rendah dan boleh dihasilkan dalam kuantiti yang banyak. Projek ini memfokuskan kajian tentang Antena Mikrojalur dan untuk merekabentuk antena tersebut dengan menggunakan FR4 dan Roger4350. Frekuensi yang dipilih bagi antenna ini adalah 2.4GHz yang telah dipilih dari IEEE 802.11 bagi rangkaian WiFi. Projek ini dibahagikan kepada tiga bahagian utama iaitu pengiraan, simulasi dan fabrikasi. Perisian komputer yang digunakan bagi merekabentuk antena ini adalah CST dan digunakan untuk menganalisis corak sinaran antena sebelum difabrikasi. VNA digunakan untuk mengukur antenna yang telah difabrikasi bagi memastikan antena tersebut boleh berfungsi dalam frekuensi yang telah ditetapkan. Keputusan simulasi dan pengukuran menunjukkan terdapat sedikit perbezaan bagi kedua-dua jenis bahan yang digunakan. Perbandingan diantara hasil simulasi dan hasil pengukuran telah dibuat.

CONTENTS

TITLE	i
DECLARATION	ii
DEDICATION	iii
ACKNOWLEDGEMENT	iv
ABSTRACT	v
ABSTRAK	vi
TABLE OF CONTENTS	vii
LIST OF TABLE	x
LIST OF FIGURE	xi
LIST OF SYMBOL AND ABBREVIATIONS	xvi
LIST OF APPENDIX	xvii

1 INTRODUCTION

1.1	Background Study	1
1.2	Problem Statements	3
1.3	Objectives	4
1.4	Scope	4

2 LITERATURE REVIEW

2.1	Overview	5
-----	----------	---

2.2	Basic of Antenna	5
2.3	Microstrip Antenna	6
2.3.1	Feed Technique	7
2.4	Antenna Properties	8
2.4.1	Radiation Pattern	8
2.4.1.1	Principal Pattern	8
2.4.1.2	Radiation Pattern Lobes	8
2.4.2	Directivity	9
2.4.3	Gain	10
2.4.4	Half-Power Beamwidth	11
2.4.5	Bandwidth	11
2.4.6	Input Impedance	11
2.4.7	Polarization	12
2.4.8	Reflection Coefficient	13
2.4.9	Voltage Standing Wave Ratio (VSWR)	13
2.5	Analysis for Transmission Line Model	14
2.5.1	Coaxial Probe Feed	17
2.6	Wireless Local Area Network (WLAN)	17
2.7	Previous Study	18
3	METHODOLOGY	
3.1	Introduction	26
3.2	Design of Microstrip Antenna	26
3.3	Software Implementation	28
3.3.1	Computer Simulation Technology (CST) Studio Software	29
3.3.2	Auto Computer Aided Design (CAD) Software	30
3.4	Microstrip Antenna Design	30
3.4.1	Determination of Antenna Dimension	30
3.4.2	Shape of Microstrip Antenna	32
3.4.3	Design Microstrip Antenna using CST	33
3.4.4	Port Creation of the Microstrip Antenna	45
3.5	Fabrication	51
3.5.1	Antenna Layout Printing	51
3.5.2	Laminating and UV Light Process	53

3.5.3	Developing Process	54
3.5.4	Etching Process	54
3.5.5	Stripping Process	55
3.5.6	Soldering Process	55
3.6	Measurement	56

4 RESULT AND ANALYSIS

4.1	Simulation Result	57
4.1.1	Antenna Geometry Construction Parameters	58
4.1.2	Return Loss	58
4.1.3	Input Impedance	59
4.1.4	Voltage Standing Wave Ratio (VSWR)	60
4.1.5	Bandwidth	61
4.1.6	Radiation Pattern	62
4.1.7	Gain	65
4.1.8	Directivity	66
4.2	Measurement Result	67
4.2.1	Return Loss	67
4.2.2	Input Impedance	69
4.2.3	Radiation Pattern	70
4.2.4	Voltage Standing Wave Ratio (VSWR)	71
4.3	Comparison between FR4 and Roger4350	73

5 CONCLUSION AND RECOMMENDATION

5.1	Conclusion	76
5.2	Recommendation of Future Work	77

REFERENCES	78
-------------------	----

APPENDIX

A

B

LIST OF TABLE

Table no		Pages
2.1	Comparison between different substrate	19
2.2	Circular polarized microstrip patch antenna results	24
3.1	Material characteristic of dielectric constant and height	31
3.2	Antenna dimension based on difference material	31
4.1	Final dimension of antenna design parameters	58
4.2	Comparison between FR4 and Roger4350	75

LIST OF FIGURE

Figures no	Page
Chapter 1	
1.1 Side view of microstrip patch antenna	3
Chapter 2	
2.1 Microstrip Patch Antenna Structure	6
2.2 Coaxial Feed of the Antenna	7
2.3 Radiation Pattern of a Generic Directional Antenna	9
2.4 A Rectangular Microstrip Patch Antenna	14
2.5 A patch excited using coaxial cable	15
2.6 Feed Point for a Probe Fed-Patch	17
2.7 Antenna Design	20
2.8 S-Parameter Magnitude in dB (Return loss)	21
2.9 Layout of the one-sided directional slot antenna	21
2.10 Comparison of the measured and simulated return loss of this antenna	22
2.11 Proposed Antenna Layout design and Photograph of a Patch Antenna on FR4 PCB	22
2.12 Simulated result of return loss characteristic	23
2.13 Measured results of return loss	23
2.14 The proposed geometry of patch antenna	24
2.15 S_{11} Parameter vs Frequency Plot	25
Chapter 3	
3.1 Flowchart of the overall project	27

3.2	Microstrip antenna design	32
3.3	CST Microwave Studio	33
3.4	Workspace of the CST Microwave Studio	34
3.5	List of antenna design dimension	34
3.6	Local Coordinate system	35
3.7	Working plane of antenna design	35
3.8	Parameter of substrate	36
3.9	Material library window show material list	37
3.10	Substrate Design	37
3.11	Bottom part view of Antenna Design	38
3.12	Pick Face to highlight Face	38
3.13	Bottom substrate face highlighted	39
3.14	Local Coordinate Aligned	39
3.15	Ground Plane parameter design	40
3.16	Ground Plane Shape	40
3.17	Front Face of substrate	41
3.18	Local Coordinate system of front face substrate	41
3.19	Parameter of Patch Design	41
3.20	Patch design	42
3.21	Parameter for Empty space	42
3.22	Shape intersection window	43
3.23	Empty space on patch of the antenna design	43
3.24	Microstrip Line design	44
3.25	Microstrip Line create on front face	44
3.26	Navigation Tree part	44
3.27	Patch and microstrip line of antenna design	45
3.28	Zoom image	45
3.29	Port Design	46
3.30	Waveguide Port	46
3.31	Waveguide Port Window	46
3.32	Port system of Antenna design	47
3.33	Units Window	47
3.34	Frequency range setting	48
3.35	H-Field and Surface current	48

3.36	Farfield/RCS	49
3.37	Time Domain Solver	49
3.38	Time Domain Solver Parameter Window	50
3.39	Progress Part of the Simulation Process	50
3.40	Message Part of the Simulation Process	50
3.41	Pick Face on modelling menu	51
3.42	Pick Face on patch and substrate	52
3.43	Save as DXF format	52
3.44	Printed Layout of the antenna design	53
3.45	Laminating Process	53
3.46	Developing Machine	54
3.47	Etching Machine	54
3.48	Stripping Machine	55
3.49	Soldering Process of antenna feed	55
3.50	Vector Network Analyzer (VNA)	56
3.51	Anechoic Chamber Room	56

Chapter 4

4.1	Simulation result of return loss for FR4	59
4.2	Simulation result of return loss for Roger 4350	59
4.3	Simulation result of smith Chart for FR4	60
4.4	Simulation result of smith Chart for Roger4350	60
4.5	Simulation result of VSWR for FR4	61
4.6	Simulation result of VSWR for Roger 4350	61
4.7	Simulation result of Bandwidth for FR4	62
4.8	Simulation result of Bandwidth for Roger 4350	62
4.9	3D radiation pattern for FR4	63
4.10	3D radiation pattern for Roger 4350	63
4.11	E-Plane for FR4 substrate	63
4.12	E-Plane for Roger 4359	64
4.13	H-Plane for FR4 substrate	64
4.14	H-Plane for Roger 4350 substrate	65
4.15	Simulated gain for FR4 substrate	65
4.16	Simulated gain for Roger 4350 substrate	66

4.17	Simulated directivity for FR4 substrate	66
4.18	Simulated directivity for Roger 4350 substrate	66
4.19	Measurement result of return loss for FR4	67
4.20	Measurement result of return loss	68
4.21	Comparison between simulation and measurement result of return loss FR4	68
4.22	Comparison between the simulation and measurement result of return loss for Roger4350	69
4.23	Measured input impedance for FR4	70
4.24	Measured input impedance for Roger 4350	70
4.25	Measured radiation pattern for FR4	71
4.26	Measured radiation pattern for Roger 4350	71
4.27	Measured VSWR for FR4 substrate	72
4.28	Measured VSWR for Roger 4350 substrate	72
4.29	Comparison between the simulation result of return loss for FR4 and Roger4350	73
4.30	Comparison between the measurement result of return loss for FR4 and Roger4350	74



LIST OF SYMBOL AND ABBREVIATIONS

ϵ_r	-	Dielectric relative constant
μ_o	-	Permeability in free space
ϵ_{eff}	-	Effective dielectric constant
ϵ_0	-	Dielectric constant in free space
Ω	-	Ohm
Γ	-	Reflection coefficient
ΔL	-	Patch length extension
B	-	Bandwidth
C	-	Speed of light 3×10^8
W	-	Width
L	-	Length
F	-	Frequency
dB	-	decibel
VNA	-	Vector Network analyzer
MHz	-	Megahertz
GHz	-	Gigahertz
VSWR	-	Voltage standing wave ratio

LIST OF APPENDIX

NO	TITLE	PAGE
A	Gantt Chart PS1 and PS2	80
B	Data of Simulation and Measurement Result	82



PT TA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

CHAPTER 1

INTRODUCTION

1.1 Background of Study

In high-performance like aircraft, spacecraft, satellite and missile application, where sizes, weight, cost, performance, ease of installation, and aerodynamic profile are constraints, low profile antenna may be required. Presently there are many other government and commercial application, such as mobile radio and wireless communications, which have similar specifications. Microstrip patch antenna can be used based on these requirements. This antenna are low profile, conformable to planar and non-planar surface, simple and low cost to manufacture by using a modern printed-circuit technology. Microstrip antennas consist of a patch of metallization on a grounded substrate. These are low-profile, lightweight antennas, most suitable for aerospace and mobile applications. Because of their low-power handling capability, these antenna can be used in low-power transmitting and receiving applications [1].

Wireless technology is a truly revolutionary paradigm shift, enabling multimedia communication between people and devices from any location. Wireless communications is by any measure, the fastest growing segment of the communications industry. As such, it has captured the attention of the media and the imagination of the public [2]. Modern wireless communication systems require low profile, lightweight, high gain and simple

structure antennas to assure reliability, mobility and high efficiency. There are many parameters are important in designing the microstrip antenna. Dielectric substrate is the main parameter in design purpose.

One types of wireless communication at 2.4GHz is Wireless Fidelity (WiFi). It is enable devices such as smartphone, personal computer, video game console or digital audio player can connect to the internet if within range of a wireless network connected to the internet. The microstrip antenna was drawn the maximum attention of the antenna community in recent year. A microstrip antenna is very simple in construction using a conventional microstrip fabrication technique. Microstrip antennas consist of a patch of metallization on a grounded electric substrate. There are low profiles, lightweight antennas, most suitable for aerospace and mobile applications. The conducting patch can be any shape but the most commonly used configurations are circular and rectangular configurations.

Deschamps first proposed the concept of microstrip antennas in 1953 but practical antennas were developed by Munson and Howell in 1970s [3]. Increasing requirements for personal and mobile communications has made the microstrip antennas very important. Microstrip antenna are becoming a popular choice for portable wireless system since they are light weight, low cost and easily manufacturable [4].

It is also can be applied in Wireless Local Area Network (WLAN) application. Wireless Local Area Networks (WLANs) use electromagnetic radio waves to transmit data between computers in a Local Area Network (LAN), without the limitations set by wired network cable or phone wire connection. These 802.11 Wireless Local Area Network (WLAN) systems may operate at 2.4GHz [4].

Microstrip patch antenna can take a variety of forms, but the basic element consists of a single patch of conductor on the upper surface of a grounded dielectric substrate. The patch radiates efficiently when it is resonant, which generally means that some

characteristic dimension of the patch is nearly equal to one-half wavelength in the substrate medium [5].

The shape of the patch can be rather arbitrary, but rectangular and circular patches have several desirable characteristics and more often used in practice [5]. Figure 1.1 shows the side view of simple microstrip patch antenna. The simple microstrip antenna consists of three layers which are substrate, patch layer and ground layer.

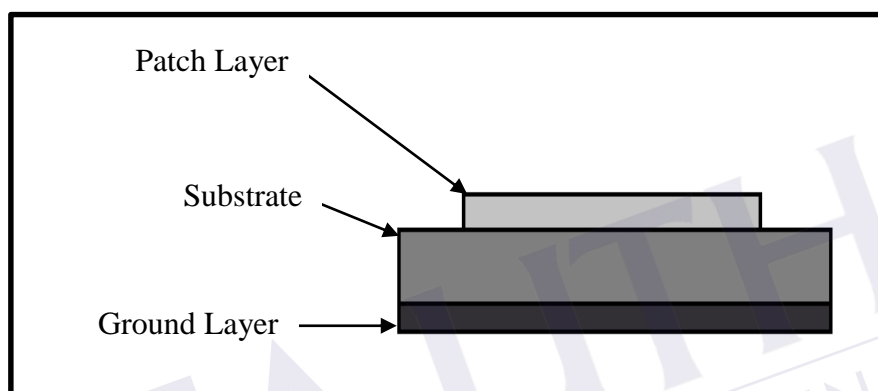


Figure 1.1 : Side view of microstrip patch antenna.

1.2 Problem Statement

Antenna is develop in order to fulfill the problem occur and upgraded the antenna for the advanced technologies. A conventional antenna is very hard to design compared to microstrip antenna. A conventional antenna is very costly and quite heavy but the microstrip patch antenna has a simple structure and quite easy to fabricated. There are many shape of microstrip patch antenna such as rectangular, circular, triangular and other types of geometries. The most popular configuration is rectangular microstrip patch antenna. In order to produce antenna for Wireless Local Area Network (WLAN) application, based on the factor, a rectangular microstrip patch antenna will be designed. This project will used the Flame Retardant 4 (FR4) and Roger4350 as a dielectric substrate in fabrication of the antenna.

1.3 Objective

- i. To design a microstrip antenna for Wireless Local Area Network (WLAN) application with frequency of 2.4GHz.
- ii. To simulate the antenna design by using Computer Simulation Technology (CST) Microwave Studio.
- iii. To fabricate the microstrip antenna by using Flame Retardant 4 (FR4) and Roger4350 substrate.
- iv. To investigate the performance of the antennas in term of return loss, operating frequency, bandwidth and Voltage Standing Wave Ratio (VSWR).

1.4 Scope

The main scope of this project consist of two parts which is software and hardware design. For the simulation part, a Computer Simulation Technology (CST) Studio will be used in order to design a rectangular microstrip patch antenna. For the hardware part, a rectangular microstrip patch antenna will be fabricated by using the different materials which is Flame Retardant 4 (FR4) and Roger 4350. The Network Analyzer will be used to measure S11, input impedance and Voltage Standing Wave Ratio (VSWR) while for the radiation pattern will be measured in anechoic chamber.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

This chapter reviews some similar previous work, related journals and researches which include microstrip antenna design that can contribute an ideas for completing this project. This chapters also will discuss about the performance of the antenna and the material that has been used to fabricate the antenna. This chapter is very important to know the performance of the antenna and to get a better performance of the antenna compared to the conventional antenna.

2.2 Basic of Antenna

There are many basic types of antenna element such as the dipoles, horn, slot, spiral, long wire, monopole, and there are also many different types of systems where these element can be arrange in some form of an array, either fixed or electronically controlled. Thus, the antenna can be divided into four types depends on their operating frequency, characteristics and capability. The groups are resonant antenna, broadband antenna, aperture antenna and electrically small antenna.

2.3 Microstrip Antenna

In its simplest configuration, microstrip antenna consist of radiating patch on one side of a dielectric substrate which has a ground plane on the other side. The patch conductors normally is copper or gold. The radiating patch and feeding lines is usually photo etched at the dielectric substrate [6]. Figure 2.1 shows the structure of the microstrip patch antenna.

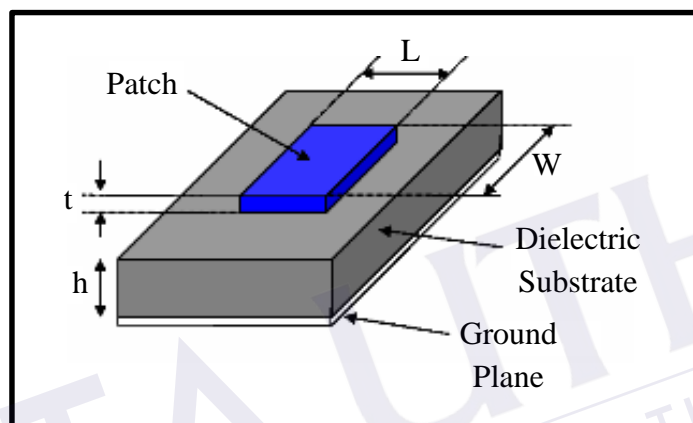


Figure 2.1 : Microstrip Patch Antenna Structure.

Based on the Figure 2.1, it shows the common microstrip antenna structure where W is the width of the patch, L is the length of the patch, t is the thickness of the patch and h is the height of the substrate. To achieve the great in antenna performance, a thick dielectric which have a low dielectric constant is needed. This will provide higher efficiency, larger bandwidth and greater radiation. But, in order to achieve this, larger antenna size will be produced. In order to reduce the size of the antenna which mean to produce a compact design, a higher dielectric constant which is less efficient and will contribute a narrower bandwidth will be used [6].

Microstrip antenna has several advantages compared to conventional microwave antenna. These types of the antennas are light weight, low volume and thin profile configurations, which can be made conformal. The cost of fabrication is also low. So, it can be manufactured in a large quantities [6]. For the polarization types, it can support

both linear and circular polarization depending on the radiation pattern. Microstrip patch antenna also capable of dual and even triple frequency operations [6]. On the other hand, microstrip patch antennas also have some disadvantages. These type of antenna have a narrow bandwidth, low efficiency and also have a low gain [6].

2.3.1 Feed Techniques

Microstrip antenna feed techniques can be categorized in two categories which are contacting and non-contacting. In the contacting method, the RF Power is fed directly to the radiating patch using a connecting element such as a microstrip line. The microstrip line and the coaxial probe are examples of contacting method.

In the non-contacting, electromagnetic field coupling will be done to transfer the power between the microstrip line and the radiating patch. Techniques that are in these non-contacting methods are aperture coupling and proximity coupling [6]. The feed technique that was used in this project is the microstrip line feed. However, for the coaxial feed, it can be placed at any location to match with its input impedance. It provides narrow bandwidth and it is difficult to model. Figure 2.2 shows the coaxial feed of the antenna [6].

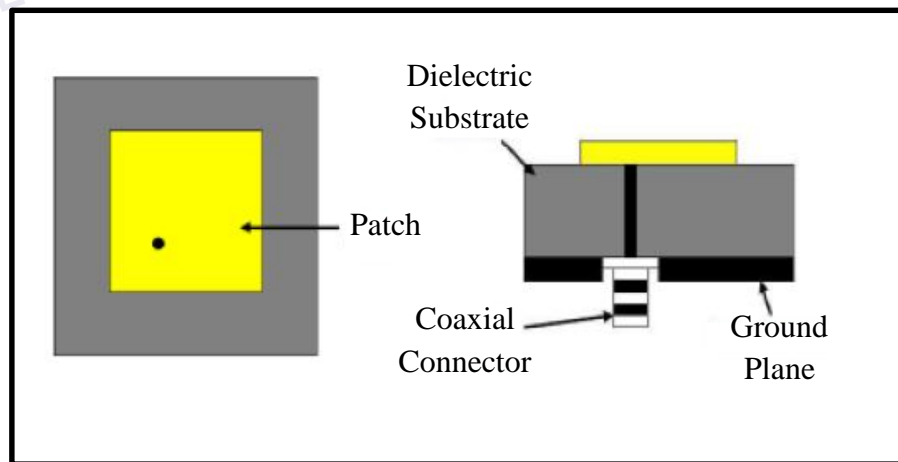


Figure 2.2 : Coaxial Feed of the Antenna.

2.4 Antenna Properties

The performance of the antenna can be determine by this important parameters which is radiation pattern, directivity, gain, half-power beamwidth, bandwidth, input impedance, polarization, reflection coefficient, Voltage Standing Wave Ratio (VSWR) and return loss.

2.4.1 Radiation Pattern

It is defined as a mathematical function or a graphical representation of the radiation properties of the antenna as a function of space coordinates. The radiation property of most concern is the two or three-dimensional spatial distribution of radiated energy as the function of the observer's position along a path of surface of constant radius [7].

2.4.1.1 Principal Patterns

For a linearly polarized antenna, the performance is usually described in terms of its principal E-plane and H-plane patterns. The E-plane is defined as the plane containing the electric-field vector and the direction of maximum radiation. The H-plane is defined as the plane containing the magnetic-field vector and the direction of maximum [7].

2.4.1.2 Radiation Pattern Lobes

A radiation lobe is a portion of the radiation pattern bounded by regions of relatively weak radiation intensity. A major lobe also called as the main beam is defined as the radiation lobe containing the direction of maximum radiation. A minor lobe is any lobe except a major lobe. A side lobe is a radiation lobe in any direction other than the

intended lobe. Usually a side lobe is adjacent to the main lobe and occupies the hemisphere in the direction of the main beam. A back lobe is a radiation lobe which the axis makes an angle of approximately 180 degrees with respect to the beam of an antenna [7]. Figure 2.3 shows the radiation pattern of a generic directional antenna.

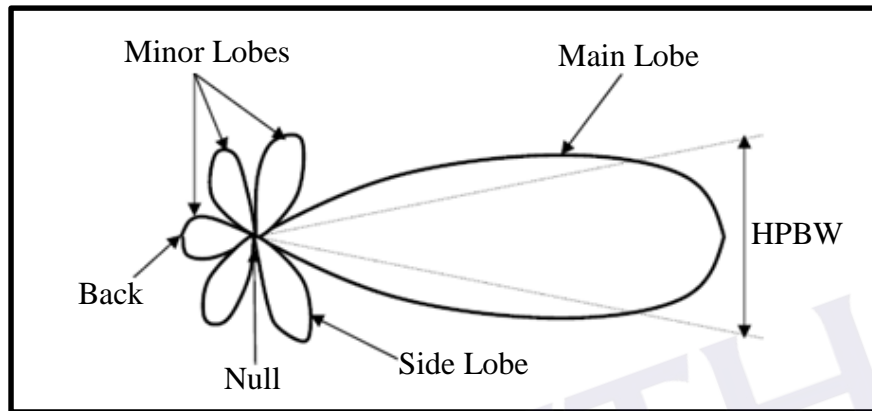


Figure 2.3 : Radiation Pattern of a Generic Directional Antenna.

2.4.2 Directivity

Directivity can be defined as the ratio of the radiation intensity in a given direction from the antenna to the radiation intensity averaged of all directions. The average radiation intensity is equal to the total power radiated by the antenna divided by 4π . If the direction is not specified, the direction of maximum radiation intensity is implied [7]. If the direction is not specified, the direction of maximum radiation intensity can be expressed as

$$D_{max} = D_o = \frac{U_{max}}{U_o} = \frac{4\pi U_{max}}{P_{rad}} \quad (2.1)$$

Where

D = directivity (dimensionless)

D_o = maximum directivity (dimensionless)

U = radiation intensity (W/unit solid angle)

REFERENCES

- [1] Ramesh Garg, Prakash Bhartia, Inder Bahl, Apisak Ittipiboon, "Microstrip Antenna Design Handbook", Artech House, 2001.
- [2] Andrea Goldsmith, "Wireless Communication", Cambridge University Press, 2005.
- [3] Girish Kumar and K.P.Ray, "Broadband Microstrip Antenna", Artech House Boston, London, 2003.
- [4] P. Nicopolitidis, "Wireless Communication System", John Wiley, 2003.
- [5] David M. Pozar and Daniel H. Schaubert, "Microstrip Antennas: The Analysis and Design of Microstrip Antennas and Arrays", John Wiley, 1995.
- [6] Ahmad Mabrook Ali Saad, "Chapter 3, Dual-Band Microstrip Loop Antenna for Wireless Application", (Unpublished), 2013.
- [7] Constantine A. Balanis, "Antenna Theory" (2nd Edition) JohnWiley & Sons, INC, Canada, 1997.
- [8] J.R Jame,P.S Hall and C.Wood, "Microstrip Antenna Theory and Design", London, United Kingdom, Peter Peregrinus, 2006.
- [9] Kraus, Marhefka, "Antenna for All Application", (3rd Edition), Ed. McGraw-Hill, 2002.
- [10] Vajha.S and Prasad,S.N, "Design and Modelling of a Proximity Coupled Patch Antenna", Conference of on Antenna and Propagation for Wireless Communication, 2000.
- [11] Mohammad Ilyas and Syed Ahson, "Handbook of Wireless Local Area Networks: Applications, Technology, Security and Standards", 2008.
- [12] Kiran Jain, Keshav Gupta, "Different substrate use in microstrip patch antenna- A Survey", International Journal of Science and Research (IJSR), 2012.
- [13] O. Bayarmaa, Kab-ki Kim, Young-Hun Lee, "Design of triple-band Planar Inverted-F Antenna for 0.9/2.4/3.6GHz Wireless Application", International Journal of Multimedia and ubiquitous Engineering, 2014.

- [14] Haruici Kanaya, Masataka Kato, R.K. Pokharel, Keiji Yoshida, “Development of 2.4GHz One-Sided Directional Planar Antenna with Quarter Wavelength Top Metal”, Institute of Electrical and Electronic Engineering (IEEE), 2010.
- [15] T. Jayachitra, V.K Pandey, Anshuman Singh, “Design of microstrip antenna for WLAN application”, International Conference on Signal Processing, Embedded System and Communication Technologies and their applications for Sustainable and Renewable Energy (ICSECSRE), April 2014.
- [16] Pradeep Kumar, Neha Thakur, Aman Sanghi, “Microstrip Patch Antenna for 2.4GHz Wireless Applications”, International Journal of Engineering Trends and Technology (IJETT), 2013.
- [17] Tan Yee Mun, Chan Yee Kit, Koo Voon Chet Mohammad Tariqul Islam A “Novel Wideband Antenna for Dual Band WLAN Application”, Institute of Electrical and Electronic Engineering (IEEE), 2010.

